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Analysis of Power-Efficient High Torque Solar Tracker through PID Controller

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***Abstract*—To provide a continuous supply of electricity, renewable energy resources, and smart technological innovation must be exploited, aiming to provide a long-term solution to the existing energy crises faced by today's world. The photovoltaic (PV) panels are deployed to receive solar energy from the sunlight and consequently convert it into electrical energy. The photovoltaic PV panel receives maximum solar radiation only when it is at 90° perpendicular to the sunlight, which is directly proportional efficiency of the system. If proper technique not used to collect the maximum amount of sunlight, solar PV generation can be a more expensive energy source as compared to conventional energy generation. The generated output power of PV panels depends on the quantity of solar energy they collect from sunlight, and this amount can be increased by exploiting tracking systems. The solar tracker tends to move PV panels perpendicular to sunlight radiations to collect the maximum amount of sunlight to increase the system's efficiency.**

Keywords-Solar panel; Photo Voltaic; Solar Tracking System; PID Controller; Solar Help Plug-in Hybrid Electric Tracker

I. Introduction

Electricity is one of the basic requirements for the development of a country. The fact is that the use of electric energy in every field of life demand for electric power is increasing due to the installation of more and more industries to fill full the individual requirement. Therefore, in order to fill full, the increasing energy demand for electricity, electric power is generating in different ways and from different sources. Now, the primary resources of electrical power are hydel and fossil fuels such as oil and coal. Traditional resources of electric power generation are not environmentally friendly.

On the other hand, they are situated at a large distance from the place where they are used, hence transmission cast and power dissipation are the factors that are to be of concern. The environmental changes faced by the world forecast are the depletion of the aforementioned sources. Therefore, it is a common fear that the current sources of energy might be depleted soon [1]. However, those sources of electric energy that are of the low cast and exist forever are needed. Also to get ride-off transmission cast and power loss they should be located at a suitable geographic position. To provide a continuous supply of electricity, renewable energy resources, and smart technological innovation must be exploited aiming to provide a long-term solution to the existing energy crises faced by today's world. Like other countries, Pakistan is also facing severe energy distress and the resources which exist forever is one of the good options to overcome these shortages of electric power that arises from the rapidly terminating fossil fuels [1]. The renewable solar energy has been noticed as an abundant power source since the last two decades and is presently used in commercial as well as in-home appliances [2]. If proper technique is not used to collect the maximum amount of sunlight, the solar PV generation expensive as compared to conventional energy, power generation from solar cells depends on the quantity of solar energy collected from sunlight by solar panels and this amount can be increased exploiting tracking systems [3]. To abstract the most efficiency from a Photovoltaic panel, nowadays trackers are used to getting sun location to make sure that sunlight is continuously on 90 degrees to the face of the photovoltaic module [4]. In literature, there are many works presented by many researchers on the methodology of the solar tracking system. Mousazadeh et al. (2011) enhance solar output expanded vitality increase cluster solar cells by fitting and planning a board based on sun-tracking on a Solar Help Plug-in Hybrid Electric Tractor (SAPHT), a based on mobile phones sun oriented tracking utilizes Light Dependent Resistors (LDRs) four in number subordinate on the tracker framework of sun oriented. Utilizing the cell phone on SAPHT, time, what is more, the date in the framework was restored. Four LDRs were employed to evaluate solar power and based upon microcontroller electric drive filled in when product equipment connects. Exploratory outcomes demonstrated that the created sun oriented tracker expanded vitality outcome by 30% contrasted with non-movable framework. The tracker expends a limit of 1.8% of the aggregate gain [5]. A few solar trackers utilized secondary photovoltaic cells that were associated legitimately to the motor having Permanent Magnet DC (PMDC) with a single pivoting hub providing electrical power necessary for the following [6]. Mazen et al. experimentally investigated the outcome of using dual-axis solar tracker systems in Jordanian weather. From experiments, authors concluded that improvement in energy gain was 30 % to 40 % while using a double-axis photovoltaic system as compares to single-axis photovoltaic systems [7]. The literature demonstrates that, in contrast to non-movable modules, the outcome of tracking systems is diverse at the start of the day and during the evening, and vitality output is about 30% high in the following frameworks[8]. Ruelas et al. (2013) actualized and broke down the double hub framework. Framework comprised of sensors of a video handling that were associated with a microcontroller, which utilized a calculation to find the geographical position of Sun's. The focal point of physical mass of the sun-powered picture was utilized to demonstrate sun development bearing. The outcome demonstrated that average following precision was at angle 0.0135° for point and at angle 0.0196° for tallness [9].

The sun has two types of motion relative to the earth, so it makes two types of angles one with the horizon and the second one with radiation trajectory. The early movement is from east to west during the whole day. In this type of motion, there is a change in the azimuth angle of the sun. In the second type of movement, it makes another angle include location height compare to the Earth, which changes day by day, i.e., from the previous day to the current day and from the current day to the coming day. That is the reason that the solar tracking system requires freedom in two angles to capture solar radiation at regular instant [10, 11].

In this paper, the effect of the electrical power system and its shortfall, like renewable energy. Section II illustrates the proposed method in detail. Section III provides the results of the framework, and Section V is the conclusion.

II. Methodology

The research methodology used for a solar tracker with the approach used in a process. Design of the solar trackers with the implementation of the software control systems with a combination of hardware components [12]. The arrangement comprises in the way of sensors that gives signals to the microcontroller comparator, the microcontroller circuit for decision making, a motor drive circuit for high current the DC motors that will move accordingly in both directions with coordination to the mechanical structure [12].

This equipment is bringing together, and the microcontroller is programmed with an algorithm to make possible the structure on which the PV cells (mounted).

A. *The Prototype/ Hardware Design*

The Figure shows the solar tracker front view and side view the assembled in a way that a PV panel is mounted on the tracker in such a way that it can move in the double-axis direction, e.g. (East to west and west to east) with the help of Motor-1 and rotation in the other direction (North to South and South to North) will be done with the help of Motor-2 in the figure describes.

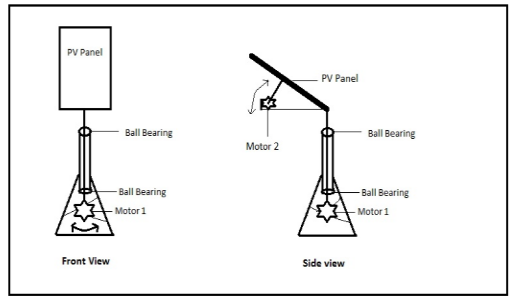

Figure 1. Showing Front view and Side view of the Double Axis Solar tracker

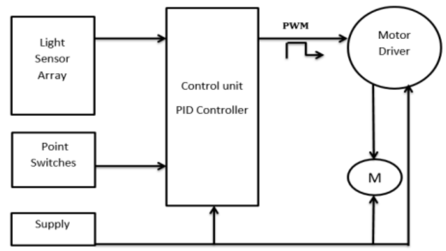

Figure 2. The Block diagram

The figure describes the design; the whole design structure has been manufactured ferrite structure to overcome the loading of wind and robustness. The above parts of the prototype discussed in order to apply for the manufacturing of automatic solar trackers with the help of the following materials such as LDR sensors, Arduino Uno, DC motor, potentiometer, limit switches, and a panel for the prototype. In addition to the process and to utilize the prototype concept PV panels of 30W is used for the analysis of the maximum efficiency on large scale PV solar projects as shown in Figure 3: As shown, the entire test bench, a dual-axis solar tracker and that can expose to the sunlight to test the solar tracker test bench. When once the voltage for PV attained, then the controller will get this information and utilized this data to calculate the current for PV and power. It can provide ways for the researchers, engineers, and students to apply their algorithms easily and then proceeding with broad solar tracking devices implementation.

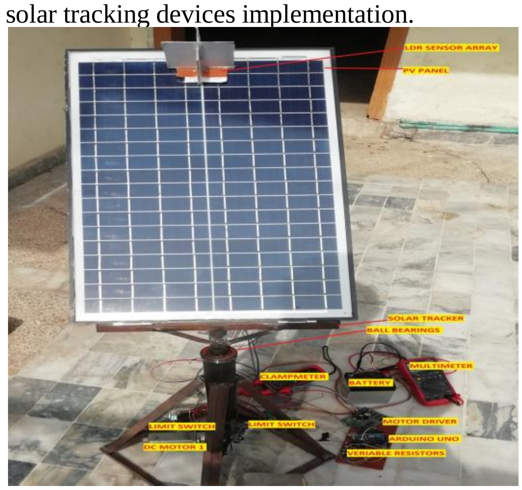

Figure 3. The Block diagram

III. RESULTS & DISCUSSION

The performance of the solar tracker can be calculated and will compare with the existing systems presented by the scholars in their work for efficiency improvement. This process is carried out firstly with fixed structure results, after the results of fixed structure, the process preceding towards SAT, and compared with the result of the double-axis tracker. The respective systems voltage (V) values and current (I) were measured hourly from 06:00 HRS to 18:00 HRS for four weeks, i.e., May 1, 2019, to May 30, 2019, with the help of solar system based company in Peshawar, Khyber Pakhtunkhwa. The data that has achieved during the experiments were latterly analyzed for determining the output power results, compared to the fixed tracker, single-axis tracker, and compared to Timothy Laseinde and Dominic Ramere. The results achieved from the experiments and then tabulated its values and demonstrated in the graph. Naturally, the position of the sun varies during day time east to west and north to south yearly. The varying sun position, the fixed structure PV panels (although having low-cost and simplest structure), does not remain perpendicular to the sunlight during each instant, which affects the system's efficiency badly. If proper technique not used to collect the maximum amount of sunlight, solar PV generation is expensive as compared to conventional energy generation. The output power of PV panels depends on the quantity of solar energy they collect from sunlight, and this amount can be increased by exploiting tracking systems [3]. To this purpose, the solar tracker used for tracking the sun. The solar tracker moves PV panel perpendicular to radiations with the aim of efficiency improvement. In experiments observed, the PV output solar modules have been increased with the help of using sun tracking. The overall daily output power gain or we can say the efficiency has increased by more than 23% of the single-axis solar tracker as comparison exceeded it by at least up to 40% when double axis tracker used. Initially, to acquire the results, the experiments have been performed on the test bench that proposed. The proposed project had been mounted for an experiment in the open air on the roof of the building that is south facing for easy detection of sunlight. The voltage level and current measured with a multimeter. The readings are as shown in Table.

TABLE I. FIXED, SINGLE AXIS, AND DOUBLE WATT STRUCTURES

Time (Hour)	Fixed Watt	Single-axis Watt	Double axis Watt
6	5	10	14
7	7	12	16
8	10	15	20
9	13	19	22
10	17	23	27
11	22	27	34
12	28	29	34
13	33	34	35
14	26	29	35
15	23	25	31
16	20	22	29
17	15	18	27
18	6	12	23

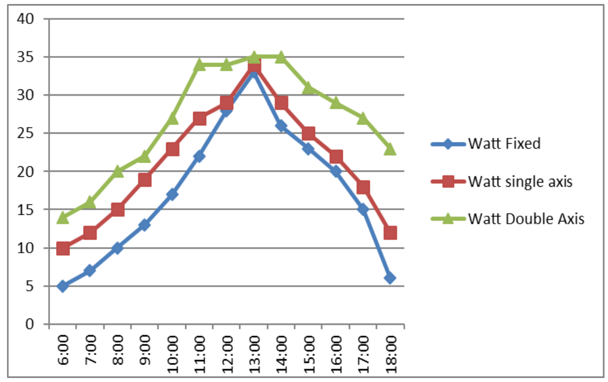

Figure 4. Fixed, Single Axis, Double Axis tracker output

The movement of the motor will consume power, and this power subtracted from the real power generated by the solar panel in all formats for net efficiency improvement. The output of the motor values discussed through a tabulated form and with graphical representation is shown accordingly.

TABLE II. TOTAL CONSUMPTION OF BOTH MOTORS

Time (Hour)	Motor 1 (Watt)	Motor 2 (Watt)	Total Watt
6	3	2	5
7	3	2	5
8	3	2	5
9	3	2	5
10	3	2	5
11	3	2	5
12	3	2	5
13	3	2	5
14	3	2	5
15	3	2	5
16	3	2	5
17	3	2	5
18	5	2.5	7.5

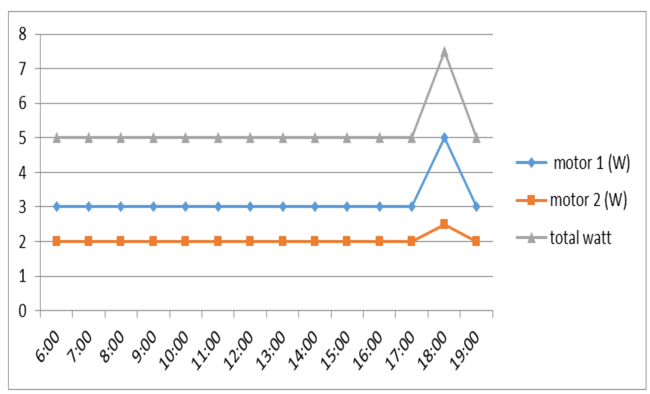

Figure 5. Total wattage of both motors

After obtaining all the outputs from the PV panel and DC motors, then subtracting motor consumption from PV output to analyze the power efficiency.

TABLE III. THE NET RESULT OF SINGLE AND DUAL AXIS

Time (Hour)	Single-axis output	Motor 1 (Watt)	Total watt (Subtract)	Dual Axis output	Motor 2 (Watt)	Total watt (Subtract)
6	10	3	7	14	5	9
7	12	3	9	16	5	11
8	15	3	12	20	5	15
9	19	3	16	22	5	17
10	23	3	20	27	5	22
11	27	3	24	34	5	29
12	29	3	26	34	5	29
13	34	3	31	35	5	30
14	29	3	26	35	5	30
15	25	3	22	31	5	26
16	22	3	19	29	5	24
17	18	3	15	27	5	22
18	12	5	7	23	7.5	15.5

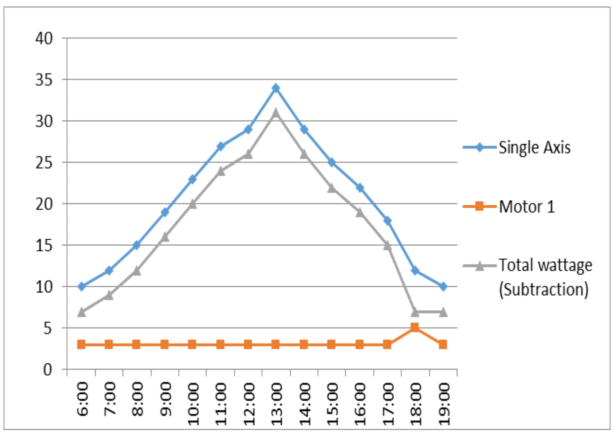

Figure 6. The Net result of Single Axis

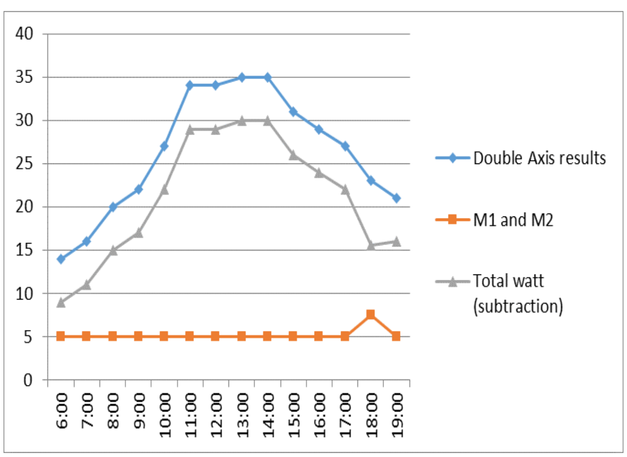

Figure 7. The Net result of Dual Axis

Results of the presented project determined from different experiments compared with the results of Timothy Laseinde, Dominic Ramere presented system and found tremendous results and massive difference of the efficiency and design difference that compensate the wind loading a lot of energy consumption. The graphs of the previous work shown below.

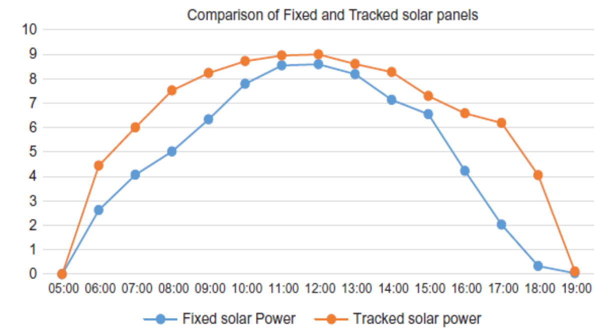

Figure 8. Output current of fixed and tracking PV panel

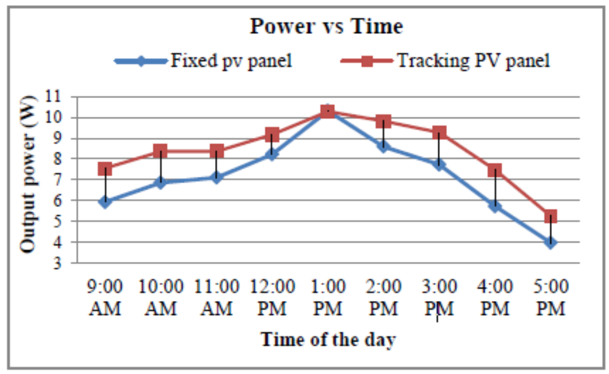

Figure 9. Output power of fixed and tracking PV panel

The experimental observations show that the average increase in energy efficiency was 12–20%. When the PV panels moved using a single-axis tracker, energy efficiency achieved when the intelligent tracker utilized accordingly.

Percentage efficiency equation = [(Dual-axis– fixed) / Dual)] x 100%

Percentage efficiency DATS to single-axis, obtained from the following equation:

$$n_{avg} = \frac{\sum (P_2 - P_1)}{\sum p_1} \times 100\%$$

Percentage efficiency = [(DATS– Single-axis) / DATS] x 100%.

This process had been repeated for comparison to receiving maximum efficiency.

The below Graphical results shows that the previous research work blue line represents fixed structure results, orange line single-axis results, and the gray line shows double-axis results. The results are in the following position; Dual Axis tracker has more energy 20% energy than the Single Axis Tracker and up to 40% more than the Fixed PV panel system.

A Unique technique used in the present system that the sun changes its position. It had shown with experiments that if the moving fixtures continuously get error signals from the sensors through microcontroller. Then it will consume more energy due to which the jerks increases in the system, here we have used a better technique to compensate jerks in the system through the mechanical structure. The microcontroller will generate an error signal if there any error the motor will move accordingly to maintain its position to get maximum energy from Sun.

A technique used for dual-axis efficiency improvement and the results latterly compared with the performance of a single-axis tracker and a fixed PV panel structure and with Timothy Laseinde and Dominic Ramere's system. In this paper, Timothy Laseinde and Dominic Ramere focus on comparing the results for optimization. The sun changing position limits the irradiation, and the solar tracker's efficiency decreases. The major limitation of solar trackers has, however, been a high cost to their implementation. For this purpose, Arduino launched for change in the MPPT algorithm with a feedback control system that increases the solar panel efficiency.

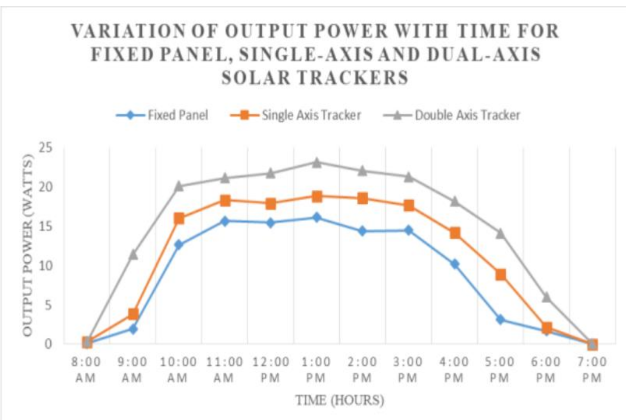

Figure 10. Previous Results

In the above-studied components are built up above studied components used to build the solar tracker for the adjustment automatically itself with the help of comparison with the algorithm that has been uploaded to the microcontroller and making decision accordingly in automatic approaches (LDR sensors, Arduino Uno, DC gear motors, potentiometer, limit switches and 35 watt PV panel for testing prototyping) in addition to the process and to utilize the prototype concept PV panels of 35W used for the analysis. Though the system that proposed is complex than single-axis solar tracker and off course while comparison with fixed panel system, the dual-axis tracking system has the advantage that makes the system unique from rest of the systems as with the comparison with the results of generated power as discussed in the methodology and terms of energy efficiency.

IV. Conclusion and Suggestion for Future Work

This work tracker has discussed with different techniques and approaches from the previous research work presented that employs in a way that differs from the rest of the systems. Their purpose is efficiency improvement implementation software control leading to hardware with the help of sensors based control system. Software control system and execution have done, and with the calculations and comparison with the help of an algorithm, the tracker adjusts the position perpendicular to the sun automatically.

The actual difference is that it frequently generated a delay signal for comparison; the signal is generated. The maximum results after excluding the value of DC motor usage from the dual and single axis real power to get net power this technique used in this process, providing high accuracy. The system continuously generates an error signal for comparison; however, in this case, the signal is generated frequently with energy consumption of the moving fixtures is reduced by this technique. This results during the position of PV panel for maximum sunlight receiving will at inclined angle dust appearance will be more. It provides the panel-cleaning object for better results.

References

[1] G. D. Valasai, M. A. Uqaili, H. R. Memon, S. R. Samoo, N. H. Mirjat, and K. Harijan, "Overcoming electricity crisis in Pakistan: A review of sustainable electricity options," Renewable and Sustainable Energy Reviews, vol. 72, pp. 734-745, 2017.

[2] M. Abdollahpour, M. R. Golzarian, A. Rohani, and H. A. Zarchi, "Development of a machine vision dual-axis solar tracking system," Solar Energy, vol. 169, pp. 136-143, 2018.

[3] I. Sefa, M. Demirtas, and I. Г‡olak, "Application of one-axis sun tracking system," Energy conversion and Management, vol. 50, no. 11, pp. 2709-2718, 2009.

[4] S. S. Eldin, M. Abd-Elhady, and H. Kandil, "Feasibility of solar tracking systems for PV panels in hot and cold regions," Renewable Energy, vol. 85, pp. 228-233, 2016.

[5] H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, and A. Sharifi, "Design, construction and evaluation of a sun-tracking system on a mobile structure," Journal of solar energy engineering, vol. 133, no. 1, 2011.

[6] Z. El Kadmiri, O. El Kadmiri, L. Masmoudi, and M. N. Bargach, "A novel solar tracker based on omnidirectional computer vision," Journal of Solar energy, vol. 2015, 2015.

[7] B.-J. Huang, Y.-C. Huang, G.-Y. Chen, P.-C. Hsu, and K. Li, "Improving solar PV system efficiency using one-axis 3-position sun tracking," Energy Procedia, vol. 33, pp. 280-287, 2013.

[8] K. S. Karimov, M. Saqib, P. Akhter, M. Ahmed, J. Chattha, and S. Yousafzai, "A simple photo-voltaic tracking system," Solar energy materials and solar cells, vol. 87, no. 1-4, pp. 49-59, 2005.

[9] A. Ruelas, N. VelГŸzquez, L. GonzГŸlez, C. Villa-Angulo, and O. GarcГ-a, "Design, implementation and evaluation of a solar tracking system based on a video processing sensor," International Journal of Advanced Research in Computer Science and Software Engineering, vol. 3, no. 10, 2013.

[10] H. Bentaher, H. Kaich, N. Ayadi, M. B. Hmouda, A. Maalej, and U. Lemmer, "A simple tracking system to monitor solar PV panels," Energy conversion and management, vol. 78, pp. 872-875, 2014.

[11] J. Sun, R. Wang, H. Hong, and Q. Liu, "An optimized tracking strategy for small-scale double-axis parabolic trough collector," Applied Thermal Engineering, vol. 112, pp. 1408-1420, 2017.

[12] T. Laseinde and D. Ramere, "Low-cost automatic multi-axis solar tracking system for performance improvement in vertical support solar panels using Arduino board," International Journal of Low-Carbon Technologies, vol. 14, no. 1, pp. 76-82, 2019.